

Intelligent System of Dynamic 2D Visualization of Passenger Flows of Public Transport Routes Based on OpenGL

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Abstract

The paper analyses existing and current scientific developments and literature sources, which show the advantages and disadvantages of many different algorithms and methods, approaches, and methods for solving problems of 2D visualization of passenger flows on public routes. As a result of the research, stable connections have been established between the factors and criteria in assessing the quality of passenger transport services.

The system analysis of the designed system is executed, and examples of the structure of an intelligent system of 2D visualization of passenger flows are created. The system's connections with the essential elements of the external world are analyzed. Our unique algorithms have been developed to display visualizations in two modes: schematic and "on the map". In the "on the map" mode, a method of calculating data on the movement of transport units on the route was successfully applied for 2D visualization on the screen, taking into account the absolute values of geographical coordinates in the world. It avoids unnecessary errors and inaccuracies in the calculations.

A neural network has been developed that operates using the RMSprop learning algorithm. The neural network predicts how the values of passenger traffic will change when adjusting the schedule of the transport unit on the route. The obtained results make it possible to form and substantiate the expediency of changing the vehicle running on the route schedule to make more efficient use of races during peak times.

Keywords 1

Passenger flows, visualization, public transport, quality of passenger traffic, JetBrains PyCharm, intelligent system, neural network

1. Introduction

The problem of dynamic 2D visualization of passenger flows is directly related to the development of intelligent systems. It contributes to developing and implementing modern technologies in the field of public transport. In the conditions of the growth of large cities, the use of modern technologies requires the creation of such means and tools [1, 2]. These tools should facilitate data exchange between critical structural elements of intelligent systems used in public transportation provision of transport services.

The main task of successful management in a market economy is to improve the quality of services. In public transport, the leading indicators of the quality of services are the transportation of passengers according to the schedule and the absence of overcrowding during peak hours. These characteristics are related to the passenger flows on the run and the passenger exchange at the stops. The main element of the passenger flow is the passenger who moves in time and space, and with the increase in the number

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of passengers, the requirements for the quality of public transportation also increase. Establishing interaction between the factors and criteria by which the quality of passenger transport services is evaluated indicates the relevance of these studies.

The research aims to manage passenger flows to increase the quality of passenger transportation and improve public transport's competitiveness for city residents. The main tasks of this study are:

1. To research and analyze existing and known algorithms, methods, approaches, and tools for solving the problems of 2D visualization of passenger flow in cities.

2. To formulate the researched problem of 2D-visualization of passenger flow, provide its justification and conduct a systematic analysis of the determined research object.

3. To choose and justify the methods and means appropriate for solving the problem of 2D visualization and forecasting changes in passenger flows when the traffic schedule changes.

4. To choose software tools for 2D visualization of passenger flows.

5. To describe the operation of the software product, where to reveal the composition and content of the functions of its operation.

6. To analyze the obtained results based on a control example of the functionality of the developed software product.

The object of the study is the process of 2D visualization of passenger flows on public transport routes. The subject of the study is the methods and principles of 2D visualization and forecasting of passenger flows on city routes.

2. Related works

In connection with the development and deepening of the globalization of the world, there is a big problem in visualizing the available data for their analysis and forming relevant conclusions. It increases the need and strengthens the urgency of creating and developing visualizations of public transport passenger flows in and between cities.

In their works [3, 4], the authors researched the impact of various traffic delays and the schedule of vehicles for transporting passengers and expressed them in the form of a simulation model that dynamically reflects the distribution of passenger flows in the networks where transportation takes place. This algorithm, created in scientific work [3], was used to visualize train passenger flows. As a result of the work carried out, the authors of the work [3] obtained specific statistical indicators, which include the basic parameters of passenger flow assessment, which are animated and visualized by appropriate software tools. The model presented in [3] visualizes the qualitative and quantitative structure of the given example of the proposed software tool.

It is essential that the method given in the work [4], which concerns the creation of a model of the actual productivity and quality of the management decision, is focused on the theoretical objective function brought to optimality. However, this happens in contrast to the centrally defined relationship between optimization and simulation, which allows for improving the objective function. This defined approach to solving the given problem justifies the need to search for new and better options and methods every time and create more effective developments applied in the real world, where modern mathematical models will be used as a basis for optimization. The authors of the paper [4] were able to determine and establish the relationship between the developed mathematical models and the natural positive result obtained when implementing the improved objective function. To confirm the processes of the obtained results, the authors [4] give many examples of the application of the developed model.

An essential feature of the work [4] is that the authors have created such a software tool that, with the help of a unique method of visualization and simulation, makes it possible to use an accurate map. This map also shows changes in the positions of transport objects over time. In addition, there is also the possibility of controlling the speed of the specified visualization.

The author of the work [5] describes the basic principles of the standard theory of motion. This theory explains where and why there are trips of various types in cities and their districts. Also, the author takes as a basis three basic concepts, namely: the frequency of passenger travel, the types of transport for movement, and, specifically, passenger boarding and disembarking locations.

The method presented in [6] attracts attention because it is focused on obtaining the dimensions of areas where transportation (departure and arrival) of transportation users takes place. Here, the amount

of transit passenger flows, which are only directed through, and not into, transportation areas, is also considered. A method created in [6] provides for the correct and high-quality division of the urban regions into transport areas, which is not always easy in practice due to the lack of coincidence of their borders and the presence of large sizes of the cities themselves. Problems with this division are further complicated by the impossibility of obtaining accurate data on objects where the main concentrations of people who want to move to occur. The author designates these places as the places of work of city residents, their places of residence and study, and gives many examples.

Features of the operation of the transport system in the conditions of an intelligent place are devoted to works [7-8], where the authors propose intelligent systems for the operation of electric transport, both piloted and unpiloted.

The authors of the [9] consider the basis of the theory of transport management based on the smart city. It is the basis for constructing forecasts of the studied passenger flows. The obtained results form the foundation of urban transport management. Forecasting passenger flows based on LSTM - long short-term memory, based on the architecture of neural networks with repetition, i.e., recurrent. The work [9] provides evidence that the increase in performance of the neural network occurs at the level of 4 to 20% when comparing it with non-hybrid models. It indicates that this model is a hybrid with optimization. This fact helps to confirm that the rationality of using the LSTM network model proposed in research [9] is high. Especially when evaluating with Nadam - fast Nesterov adaptive moment in conjunction with SGD - stochastic gradient descent algorithm for passenger flow models.

The authors [10] developed a mathematical model which allows determining the type of function of interest of a passenger in a particular route of movement within the city, but this is only in the case when there are an infinite number of ways of creating routes in this city.

In work [11], there are experiments on how passengers choose from a list of different ways and routes, precisely the one that, in their opinion, will best move them from the initial point to the final point. The studies also consider that some routes will require a transfer, and some will have a direct connection. It was also established how the conditions and quality of the trips affect such a choice. As a result of the work done, a model was created that allows you to generalize the creation of public transport network projects within the city.

At its core, authors [12] consider the issue of evaluating the performance of passenger transportation by city transport from the point of view of service provision quality. First of all, the authors [8] conducted an analytical assessment of the current methods and their parameters. They are used to determine the quality of public transport. Based on the knowledge gained, the identification of the main factors should be used for such an assessment, namely: the waiting time of passengers at the stop, the time of the trip itself in the transport, the dynamic ratio of the passenger capacity of the transport unit and the movement of pedestrians to and from the stops.

As a result, a simulation model was created in work [12], which makes it possible to determine a stable interdependence between how high-quality a trip by public transport is considered and the number of transport units in the active phase of movement on the route. As a result, this created the prerequisites for determining the number of transport units on the route that would be as effective as possible for maintaining a high quality of the provided transportation.

A significant list of works [13-18] concerns ways of creating a set of indicators to determine the effectiveness of methods used to assess the quality of transportation in public transport. It indicates the bright relevance of this issue. The authors of the work [19], in turn, already use knowledge of the normative and legislative frameworks which determine the quality of urban passenger transportation services in transport. Factors that significantly impact assessing the service quality are also determined. It is noted that the work [19] outlines the main ways and methods of increasing the rate of providing transportation services to the population by city vehicles.

In scientific works [13, 17], the primary factors and criteria by which it is possible to evaluate the quality of services are defined, namely: the waiting time of passengers at the stop, the travel time of passengers in transport, the variable coefficient of transport capacity, minimum time and real travel time data by public transport, the time spent by passengers, being in the role of pedestrians, when moving to transport stops, the routes of such movement to the stops and the total number of transfers to reach the destination.

The authors of the work [18] are convinced that for a proper and adequate assessment of the quality of services provided to passengers, researchers need to use unique SP methods, including implementing a discrete determination model, which will become the basis for creating an SQI index assessment.

In works [15, 16, 20], a study was conducted on the needs and expectations expressed by public transport users during their travels, the impact of these features on passengers' behavior, and how it generally affects the quality of services provided by carriers in this area. To generally establish certain correct conclusions, the authors of works [14, 20, 21] prefer the SERVQUAL model. This model is used to evaluate not only urban passenger transport but is also suitable for use on long-distance transportation routes.

For the SERVQUAL model, five leading indicators were defined, which made it possible to determine the relationship between the opportunities to increase the satisfaction of public transport users and accurate and effective ways to improve the efficiency of urban transport. The identified factors include empathy and feeling, sensitivity, confidence, and reliability.

Scientists in work [14] developed the SERVQUAL scale, which can already be used in many cases to understand how consumers perceive the current quality of services provided by carriers on urban public transport routes.

As a result of work [14], it can be assumed that carriers will provide high-quality transportation services, significantly impacting demand for this type of service and increasing passenger traffic. In this regard, essential links are passengers, those who use services, and carriers, those who have the ability and desire to provide such services.

The work [22] gives interesting conclusions that it is advisable to start studying the reaction and mood of passengers while waiting at a public transport stop since the choice of a passenger's route depends on it. They also indicate a relationship between the passenger's reaction during the wait and a particular route choice.

In work [23], the researchers, as a result of the work carried out, determined that the average distance traveled by a passenger in public transport has a natural relationship with the change in the value of the performance indicator of urban transport. In addition, it is also calculated here that the dimension of the passenger transportation matrix affects the average distance traveled by a passenger in the middle of the city's transport network.

The correct management and use of the public network of passenger transportation are closely related to the direction of the entire transport industry, which also, in turn, has a significant impact on the whole economic sphere in the country and is a factor of stability in the social sector.

The scientific works [24-26] investigate methods of optimization and adjustment of public transport networks in cities and urban areas. Several authors of these works also note that using three main principles is appropriate for building a systematic approach in the transport field, including decomposition, stratification, and an indication of goals. The goal is to create such a network of urban passenger transport, which would be maximally optimized using the critical values of correspondence matrices.

In work [27], a study was conducted, and as a result, it was possible to create a model for optimizing the bus network based on the transport and road network. The optimization is mainly focused on the lowest costs for transportation and the maximization of the passenger flow per unit distance, compared with the route's total length and the transport's speed, which is determined non-linearly.

The authors of the works [26, 28] managed to identify the main developments in their research, including methods of calculating labor correspondence matrices using mathematical models. It is all in the definition of the concept of intervals when creating models of demand for transportation in cities. Methods for finding intermediate states in constructed correspondence matrices are more considered explicitly in [28]. In addition, creating a separate algorithm for determining conditions was also considered for the passenger correspondence matrix. In general, the mentioned research is based on data obtained from electronic maps showing passenger traffic at the departure stations and arrival of intercity and suburban connections.

In their work [29], the authors show a purposeful interest in bus transportation in urban public transport. Therefore, this paper presents its version of building a bus network. It also considers the possible main consequences of creating, modernizing, and planning bus routes for most of the four stages.

In the scientific work [25], the authors were able to create a specific algorithm that will help solve the problem of routing transport units and optimize it. This algorithm can also manage data on the number of transport units on the route and their distribution by clusters. The basis of the research is the minimization of negative consequences that occur in cities on public transport routes and the simultaneous increase in the attractiveness of such routes for passengers.

The methods created in [30] make it possible to form public transport networks within the city and also allow me to determine what shortcomings exist in modern approaches. It is also stated that these shortcomings extend to bus-type transport networks in large cities. The model created by the authors for developing and optimizing public transport networks is based on CPACA, which stands for "Coarse-grain Parallel Ant Colony Algorithm" and is called the ant colony algorithm. This algorithm aims to maximize the number of non-stop passengers per transport unit, i.e., taking into account the direct passenger flow density indicator.

The changes in the global economic system caused by COVID-19 led to the need to adapt to new trends, maximize possible benefits and minimize negative manifestations. In a series of works [31-35], the authors consider the quality of service and customer satisfaction as critical components of the successful management of the efficiency of any business. Having studied the impact of airport service quality on passengers' desire to use their services, scientists have established a positive and significant relationship between airport service quality and the desire to spend money there. The transformation of the public transport system is also essential, as public transport systems are important elements in cities. They provide spatial mobility to at least half of the city's residents who cannot use individual transport. The proposed recommendations to local government bodies will reduce the subsidization of unprofitable carriers, transform the operation of unprofitable routes, and completely transform the city's transport service system. The researchers say the research will provide authorities with a theoretical and empirical framework to address the many factors passengers are looking for in services or may look for in the future that is currently unclear and ambiguous due to COVID-19.

Among the authors [36], who studied urban transport planning to improve the quality-of-service provision, there are supporters of using the origin-destination demand matrix for travel modeling and transport planning. The authors consider easily accessible and free socio-economic variables when evaluating urban mobility. The proposed technique has an automatic feature selection to determine the most relevant socio-economic variables, discarding irrelevant ones. To estimate mobility between predefined zones, the researchers used machine learning models, artificial neural networks, and support vector regression to test and compare using the most relevant variables as inputs. The methodology proposed by the authors can be a promising and affordable alternative for estimating origin-destination demand matrices, significantly reducing costs and execution time and helping and improving urban transport planning.

Several articles [37-38] provide an overview and analysis of the most frequently used methods and technologies and their designs used to count passengers on board public city transport vehicles. The authors believe that using sensor technology provides added value to an already existing system. The proposed review of various automatic passenger counting systems in urban transport shows how specific designs, methods, and technologies contribute to this. In addition, we reviewed the characteristics of certain technologies based on available relevant studies, in which various measures of accuracy, i.e., the accuracy of specific designs, were performed. Such information as vehicle occupancy by the number of passengers, passenger movements at stops of urban public passenger transport, and congestion on certain transport lines can be obtained using the automatic passenger counting system.

In scientific works [39], the authors propose an ISTL-LSTM model, which combines a seasonal trend decomposition procedure based on locally weighted regression (STL), several functions, and three long-term memory (LSTM) neural networks to improve the accuracy of bus passenger traffic forecasting. The ISTL-LSTM method proposed by the researchers consists of four procedures, where forecast values are generated from LSTM models and combined into the final forecast value. The developed models were tested on the example of the forecast of daily bus passenger traffic in Beijing during the pandemic. The given series of studies fills existing gaps in public transport passenger flow forecasting.

Several authors [40-41] investigated Spatio-temporal patterns that are formed through traffic flows, namely: understanding the impact of the transport system on the results of expected urban activity.

Using the example of a population study in the city of Seoul, hourly population data based on cell phone location records were analyzed in conjunction with several indicators of the Seoul subway system. Using clustering and principal component analysis, the authors found that the spatial distribution of the population is classified according to the time of day, i.e., night, day, and evening, the variations of which reflect the morphology of land use.

Some papers [40-41] analyze the Spatio-temporal characteristics of passenger flow, based on which researchers build directed weighted temporal urban mobility networks (TUMNs), where nodes are stations, and weighted links represent the number of trips between nodes. The obtained research results open the way to an expanded spectrum of real complex networks and help plan the transport infrastructure of urban transportation.

In the works of researchers [42], a subsystem for selling and controlling passenger tickets using RFID technology is proposed. Researchers believe using RFID technology speeds up the passenger boarding process, reducing traffic jams, eliminating passengers boarding the wrong line, and significantly reducing the use of cash payments.

The authors of some studies analyzed the static distribution of passenger flows in their works [42-44], where they proved that the Spatio-temporal characteristics of passengers play a decisive role in assessing the importance of a station. The developed new evaluation method, called flow topology centrality, considers the dynamics of passenger flows. The authors of the works [43-44] consider the network as a collection of load nodes, and load nodes are used to describe the time-varying characteristics of passenger flows. The experiment results make it possible to determine the importance of stations based on dynamic changes in passenger traffic, especially when passenger traffic fluctuates sharply. To avoid station overcrowding, the articles propose a new model of multiposition joint control, thanks to which all safety restrictions are achieved in the critical areas of the transfer station, and the efficiency of passenger transportation is increased. The proposed models use established routes of passenger traffic. The works include simulation experiments for stations in the Beijing subway.

In our previous works [7, 8, 45-46], we attempted to visualize passenger flows on public electric transport routes within a city with a population of up to 1 million inhabitants. The visualization performed in works [45-46] has significant drawbacks that do not allow working with routes without final stops that belong to a particular ring type. The development of such information systems must contribute to reducing CO₂ emissions [47], to improve life quality in Smart Cities [48-50] and increasing the population's ecological [47], economic [49, 50] and socio-psychological indicators [51, 52]. Others researchers [53-64] investigate features of transport services [65-78]. It is desirable that such systems should be integrated with modules based on the control and management of data from sensors and sensors [79-90].

Thus, today the problem of visualization of passenger flows in the field of public transport is insufficiently researched among the available scientific works and is weakly implemented as an intelligent system. With the growing challenges in today's world, the development of an intelligent passenger flow visualization system requires original approaches to solving the problem of improving the quality of passenger transportation in cities.

3. Analysis of the existing problem and justification of ways to solve it

The primary purpose of the developed system is to increase the quality of providing transportation services on public transport routes in various settlements, including large and small cities, which contributes to the market economy's development, improving its indicators and indices [91, 92]. It is based on the fact that the central part of all urban transportation is the passenger. The aggregate of passengers moving in transport constitutes passenger traffic. Companies' financial and economic success depends on the correctness of the assessment and analysis of passenger flows, that is, on how empty or full the vehicles are, how detailed and convenient the traffic schedule is, and how much, in general, it is followed. Even if it is impossible to follow the specified schedule, access to messages and reports to potential passengers of dynamic changes in the traffic schedule must be provided.

The designed system is proposed for use in various state and communal transport enterprises and ordinary private ones with only a few routes. They want to improve them as much as possible from the

point of view of both the quality of services provided to customers and financial benefits for the carrier company itself.

The justification for the necessity of this development is based on several aspects, starting with the fact that the industry under study is still weakly employed [93]. It is because only a few huge companies provide such services or have specialized software that they can sell on the market. The software products they offer are incredibly expensive. In our realities, usually, when it is not possible to predict a significant, significant profit from the application of the opportunities presented in the program to improve the management of passenger flows, a way is used to do it much easier and cheaper or to do nothing, not to touch at all and not to make any changes, because anyway works, although not consistently profitable.

This software tool is designed to correct this shortcoming by making it possible to gradually change the routes without considering additional risks due to unexpected effects. Although the developed system cannot have the complete set of all possible functionality provided by companies with many years of experience in the passenger flow management of software products market, the price is predicted to be tens or hundreds of times lower. It will allow carrier companies to successfully assess the quality of the provided services without hesitation, taking into account real-world events.

The next step, to confirm the need for this intelligent system, is that the quality of service by public transport directly affects the feeling of comfort not only of city residents but also of tourists. It will contribute to the ability to quickly get to those points where tourists want to leave their money.

The poor quality of the provision of such services, including the overcrowding of vehicles, their irregular movement or the impossibility of obtaining data about changes in the schedule, an inadequate number of vehicles on the route, which creates empty routes that few people need, and other factors that push the population to purchase of own vehicles. Over time, this causes the city's transport system more and more problems due to traffic jams and the need to increase the number of parking spaces. As a result, this further reduces the possibility of establishing public transport routes and building efficient transport networks with modern road interchanges.

After successfully implementing the system, transport companies can properly evaluate public transport routes and determine their efficiency using this system based on visual, graphical, and numerical data on passenger flows between stops and passenger traffic at stops. This will allow certain companies that own this software to get a visual representation of what is happening on their routes, what is the occupancy of vehicles, where are the most important boarding and disembarking nodes for passengers, and also evaluate this information on a map with anchors to important infrastructure facilities, where their high use by citizens is generated. The conceptual scheme of the designed system can be presented in the form of a set of descriptions of input and output data, functions and structure, requirements, and additional formal or generalized forms of the model.

Because the interactivity and versatility of software products are essential now in the modern world, it is vital that the system can support data that is presented according to international standards. As it is not surprising, finally, in the transport system, there is a created format, which is used by companies all over the world to present a description of all the route systems of cities along with their work schedule and other significant features. This international data format is called GTFS, which stands for "General Transit Feed Specification", and it is a publicly available format for describing not only the timetable of public transport but also the accompanying geographical information, such as the coordinates of stops and routes. It makes it possible to use the specified data format on maps successfully. Initially, this product was developed by the company Google, and later, when this format gained international status, the first letter G in the name already stood for General, not Google.

The transport company can obtain in different ways data on passenger flows. It should first be chosen to present data on passenger flows in the universal format, allowing for combining the export possibilities from various existing automatic counting systems and manual data filling by observers at stops. The most popular Excel spreadsheet editors, including open-source compatible programs that support this format, have been selected to meet the identified needs.

The specially designed program will create a template a company employee can fill out without difficulty. In this way, it is planned to universally solve the problem due to the impossibility of predicting what methods the carrier company will use to count the number of passengers. It will make it possible by providing a data submission format that can be obtained from all information collection methods.

The main task of the designed software product is to provide qualified and naturally understandable ways of visualizing passenger flows. It is specially planned to develop various schemes for providing visualized data to give these possibilities.

For example, the method of submitting the entire route with stops and dynamic filling of vehicles directly on the city map is considered. The type of presentation will allow you to visually assess which stops have the largest passenger turnover, on which routes there is overflow or insufficient filling of the rolling stock of the route, as well as to determine whether these stops are transfer stations or hubs with a high concentration of people.

In the schematic mode of presentation, greater emphasis should be placed on a large number of accompanying statistical data, which should be compatible with the schematic image of the route and provide the opportunity to also quantitatively assess the state of affairs in specific sections at specific time intervals of the day. Also, with similar content and essence, various graphs will be used in the schematic mode, showing statistical information with the necessary calculated indicators and characteristics of the selected route, section, or stop.

The structure of the system will be based on the identified implementation needs. It is planned to create a separate system unit to work with the database, where all read and processed GTFS data will be stored. It is also planned separately to create a subsystem to read GTFS data and write it to the database. Each structural unit, such as a route, stop, point, or line, will be implemented as separate objects to combine into more complex structural units. The functions planned to be used must necessarily function for working with the coordinate system and the subsequent transformation of this data into planar versions of the presentation on the screen. The general system requirements are pretty simple. Accurate processing of GTFS data and data in Excel format must be ensured. All structural objects are successfully created and must be populated with appropriate data for their visualization.

The system should allow visualization in several modes, primarily on the map and schematic with additional graph output. The neural network result should also be presented in a schematic mode for evaluating the overall results.

The generalized model of the designed system can be presented as a developed method of user interaction with the system itself. First, the system should allow the user to select an archive file with data in GTFS format from a file system. After this selection, converting this data from CSV text files, a requirement of this standard, to database format data must occur. It is expected to be an SQLite database. The next step after this data processing should be to allow the user to download a complete and available list of routes and select from it the one to be evaluated and analyzed.

Next, loading maps for the background in "on map" mode should be possible. To continue operation, the user must be offered the option to download data specifically about the selected route. As soon as this stage is completed, it should be possible for the user to create a file in Excel according to the template, which will be filled with data about the boarding and disembarking of passengers.

After the user successfully fills in this file, the option to choose the type of visualization: schematic, or "on the map", will become available. In turn, the schematic mode should provide the output of all available information about the entire route and a specifically selected stop or overrun. Also, this data should be able to be presented in graphs that will be called from this mode of operation.

A linear horizontal display of the route view with its structural elements, which can be scrolled with the mouse wheel, is provided. The "on the map" mode should be able to display the dynamics of time changes in the movement of vehicles along the route along with the boarding and disembarking of passengers at stops. The ability to change the image scale and display speed should be available.

Separately, the possibility of training a neural network based on downloaded route data and creating a file for a new transport schedule is provided, which the user will now fill only with data about the new traffic schedule. After the successful training of the network and the user filling out a new file in Excel format, it will be possible to make predictions using the trained neural network and then visualize the changed data on passenger flows in a schematic mode. It will make it possible to assess whether such a change in the traffic schedule will give more advantages or have disadvantages.

So, the specific structure of the system and its connection with the external environment were determined. The problem of 2D visualization of passenger flows is formulated and substantiated by describing a set of requirements for the designed system. The purpose of the system is outlined, which consists in improving the quality of providing transportation services on public transport routes in cities. It was determined that the place of application of the system is both state and communal enterprises and

private companies that carry out passenger transportation. The development and implementation of the system are justified by the need to reduce overcrowding of vehicles, regulate their traffic schedule, availability and availability of information about changes, etc.

4. Methods and means

4.1. Methods of working with geodata

Various methods were used in the project being developed to solve the problem, which were chosen due to their versatility and effectiveness. The main emphasis is on making the right choice of methods of working with geodata and their transformations.

The work converts coordinates from the World Geodetic System (abbreviated as WGS), namely from the latest version of WGS84, into "world" coordinates. "World" coordinates uniquely refer to a point placed on the map and to so-called "pixel" coordinates, which, in turn, refer to a specific pixel on the map on a plane with a specified zoom level.

Obtaining "world" coordinates from the format of the WGS84 version is performed according to the method below, where x and y are just the new coordinates:

```
sin_y = math.sin(self.lat * math.pi / 180)
sin_y = min(max(sin_y, -0.9999), 0.9999)
x = self.TILE_SIZE * (0.5 + self.lon / 360)
y = self.TILE_SIZE * (0.5 - math.log((1 + sin_y) / (1 - sin_y)) / (4 * math.pi))
```

Further conversion from "world" coordinates to "pixel" coordinates is performed using formula (1):

$$\text{pixelCoordinate} = \text{worldCoordinate} * 2^{\text{zoomLevel}}, \quad (1)$$

where worldCoordinate is x and y , which were obtained above;
 zoomLevel is the map display scale.

As for the methods used to create the rendering, it converts a range of numbers to another range while preserving the relationship between the numbers.

For example, this method is used in the project to determine the dimensions of the schematic marking of the line when displaying passenger flows and the size of stops when determining the volume of passenger traffic.

In the "on the map" mode, the vehicle's movement is calculated in real-time according to its movement schedule. Therefore, to create such a movement of transport on the route, a proprietary method was used, which consists of several other methods, namely:

1. The projection method (project) - returns the distance along a defined geometric object, which in this case is a line between the coordinates of the vehicle route to the point closest to another point of the route to which it is measured.

2. The interpolation method (interpolate) – returns a point at the specified distance along the line defined in the previous method between the coordinates of the points of the route of the transport unit.

Suppose such a point, which was obtained as a result of the execution of this mixed method, does not belong to the defined segment between the coordinates of the route. In that case, this method will be repeated with the following segments of the route until the segment to which the point belongs is found.

4.2. Methods of forecasting passenger flows

Since the software product predicts passenger flows, a neural network was created for this purpose. The RMSprop (root mean square propagation) algorithm is used to train this neural network, which makes predictions when the motion graph changes.

The main content of the RMSprop method is to:

- perform maintenance of the moving (reduced) mean square of the gradients;
- divide the gradient by the root from the determined average value.

In this case, the RMSprop method does not use the Nesterov pulse but the normal pulse. Also, the centered version supports moving average gradients and uses the found average to estimate the variance.

According to the methods for neural networks, it is necessary to assign a method for counting errors. In this case, the method of calculating the root mean square error was used, which has sufficient accuracy and quality relative to the given needs.

4.3. Tools for implementing 2D visualization

To solve the problem of 2D visualization of passenger flows, Python programming language was used, which is classified as a high-level object-oriented language. It allows you to use class objects and the classes themselves to build the structure of the software developed competently. According to its classification, this language refers to interpreted languages that do not require compilation before code execution, so the developed code is executed immediately.

One of the advantages of the Python language, from the point of view of writing the code itself, can be considered a clean syntax, in which indentations are used to separate functional parts of the code. Regarding the advantages of the language, it should be noted that for developing this software product, it is possible to use ready-made modules supplied in a regular assembly or from other developers and independently develop your modules that can be universalized for many needs. The third significant advantage is the ability to edit and improve already existing modules, which is an important point even at the stage of designing the developed system.

In the standard assembly of the Python distribution, many useful modules can be used to solve the given problem. The `shelve` and `pickle` modules are used for data storage and packaging. The `sqlite3` module helps to work with the database. For mathematical problems, calculations, and calculations with data, the existing standard sets of modules were implemented, including the module for working with time and timestamps `DateTime` and the additional module `dateutil`, which helped to convert time formats into various forms of presentation.

It is important to note that a significant advantage in choosing the Python programming language was the presence of a very reliable and high-performance `sqlite3` module for working with SQLite databases. This module is included in the built-in software components with the standard Python package.

The TensorFlow module is the key and most important module for neural networks and machine learning. Its constant support by developers and continuous improvement also contributed to the choice of the Python language for the development of this system.

The TensorFlow module documentation states that the core code of the module and the `tf.keras` model will "transparently" run on the same GPU without any code changes. This possibility is significant because it can reduce the load on the computer's processor, allowing it to be used for other resource-intensive tasks when the software is running. Depending on the power of the graphics processor will make it possible to accelerate the learning speed up to several times.

Version 3.9 of the Python language was used to develop the software. There is also a newer version, Python 3.10, but developing programs takes a long time and should always be based on the most stable version of the programming language. And the most important thing is that support for all necessary modules for new versions does not always appear at the same time but usually gradually, which makes it impossible to develop any software products immediately on the latest builds of language versions. Python language belongs to the class of high-level object-oriented programming languages. The main distinguishing characteristic of the chosen language is the interpretation of the code instead of compilation before its execution. However, the latter factor is present in many other high-level languages. Also, an attractive additional benefit is the availability of individual modules, or large packages of modules, which are supplied both in the standard set and from other third-party independent developer sources.

Thus, Python is considered the language for the most optimal execution of statistical and analytical analyses or studies of data sets. This advantage is used both for processing large data sets and simply for evaluating these same sets. These advantages were used in creating 2D visualization of passenger flow data using the example of city transport.

The program interface is developed using the same module as the primary visualization processes. It made it possible to simplify the need to implement additional functions and interaction methods

between modules of different developers, which usually cannot work together without specific settings for each case.

Therefore, The Python Arcade Library module (abbreviated as an Arcade) was used for this purpose. This module uses the OpenGL library version 3.3 and higher to render all primitives on the user's screen. The possibilities of using OpenGL appear only when another pyglet module creates a window to display the content.

As for the interface, the Tkinter module is also partially used for selecting files from the file system, which creates a file selection window. In the rest of the cases, only the arcade is used to display the entire rendering, based on OpenGL to display graphics primitives, even in the user interface. Part of the information submitted to the program input is transmitted in the international GTFS format for public transport routes in the following form (2):

$$stop_id, stop_code, stop_name, stop_desc, stop_lat, stop_lon, \quad (2)$$

This GTFS data structure populates the stops.txt file with stop data. To convert the GTFS data format into a format that will be stored in the SQLite database and will be suitable for further processing in the program, a single work module, which is freely available, called pygtfs, was used. Other modules are also found in the open access and cannot provide the required functions. Therefore, the choice of a module to perform this particular subtask in the software was quite simple and unambiguous in favor of this module. The pygtfs module consists of 6 structural units, each responsible for performing its work. For example, Feed is responsible for working with CCV files; Gtfs_entities – working with all entities; Exceptions – working with internal errors; Gtfs2db – converting GTFS to a database; Schedule – represents the entire database and Loader is the manager.

As it was already said in [40-45] about methods of processing input information, the Excel file format is another way of submitting data to the program input from the user. The user can edit this file with an official product from Microsoft and any other editor compatible with this extension's files.

The software product uses a particular openpyxl module to work with this file. With its help, you can read ready-made files and create them, which allows you to make the necessary template for filling in data about the passenger exchange at the route stops for the user.

The arcade module was also used to perform the primary task: visualize all passenger flows in a schematic mode and the "on the map" mode. Like the pygame module, this module is a Python language library that facilitates the creation of 2D games.

In turn, pygame is based on the raster type of graphics. The pygame module manages individual pixels very quickly and can run (run) on almost any device. But the main feature and advantage of the arcade are that it uses OpenGL specification. The OpenGL standard can quickly render sprites and offload complex functions such as rotation and transparency to the graphics card processor.

According to its description in the official documentation, this module is intended to create and develop platformers or similar games. The most crucial factor was that the arcade module uses the OpenGL library.

The main competitor for the final choice of the visualization module was the pygame module, which is usually used for more straightforward projects with few animations and features. The table 1 gives a comparative list of the two modules' data.

Table 1
Comparison list of parameters of arcade and pygame modules

Features	Arcade	Pygame
Internal graphics engine	OpenGL 3.3+ and Pyglet	SDL 2
Primitives support rotation	Yes	No
Sprites support rotation	Yes	No
Sprites support scaling	Yes	No
Camera support	Yes	No
Physics engine	Simple, platformer, and PyMunk	None

The arcade module was designed to make it easier to create games using the OpenGL library and has many narrowly focused functions and methods. The peculiarity of this module is such a concept as "sprite", which is a separate object that can be used in developed projects to display its graphic primitives at a more efficient level with more outstanding capabilities. Therefore, considering all the features of this project, the arcade is the best basis for developing a graphic representation of 2D visualization of passenger flows using the OpenGL library. The software product under development also predicts the value of passenger flows when the vehicle schedule is changed, and for this purpose, a self-created neural network is used. The TensorFlow module was used to help create a neural network. The developer of this open-source module is Google. Although Google initially created this product for its private use to develop machine learning, it is currently one of the largest and best ways to make artificial intelligence, including building and training neural networks.

For interaction with the database during the software product development, the sqlite3 module built into the standard repository of the Python language was used. This module allows the easiest and most efficient way to interact with the SQLite database. Yes, SQLite is best used for developing small applications and projects without extensive scalability. Thanks to SQLite, reading, and writing occurs from a single physical disk, and testing during development is simpler. Its capabilities satisfy all needs for interaction with the pygtfs module, which also uses SQLite as a basis for information storage. Thus, it can be concluded that SQLite is ideal for the software product being developed. And MySQL is usually needed to create large projects with many data.

So, the work analyses various methods to solve the problem. The correctness of the Python programming language choice with appropriate modules for 2D visualization of passenger flows using OpenGL, which provides the necessary level of quality of calculations and calculations, has also been successfully substantiated. The analysis of other modules was made, among which a choice was made, and the justification for their expediency in developing the project was given.

5. Results

5.1. Implementation of 2D visualization of passenger flows

The implementation of the task of 2D visualization of passenger flows and its description are designed following the norms and requirements of international standards.

The software product's full name is "Visualization of passenger flows". The abbreviated name is presented in the form of the initial letters of the name: "VP". The Windows operating system is necessary for the software tool to work correctly. You also need to have installed the Python interpreter and appropriate modules. The developed software product is created using the Python programming language. SQL queries are used to interact with the database. The developed software mainly performs the 2D visualization of passenger flows of passenger transport in the city. It has two types of visual data presentation: schematic mode (with the output of additional graphs) and "on the map" mode. For example, in Fig. 1 shows the view of displaying the route on the map with the dynamic movement of transport.

This software product also makes it possible to predict new passenger flows when the schedule of the current traffic scheme of vehicles is changed. It happens with the help of a neural network. New data created by the neural network are displayed in the schematic mode of data submission, where an example of the schematic mode is shown in Fig. 2. The route presentation style does not change. Only the numerical indicators of passenger flow change. The only functional limitation is the ability to change the traffic schedule for only one vehicle at a time.

A significant number of well-known algorithms were used for the development. Some were more customized to deal with specific, necessary tasks of the project, and some were used without modification. To convert GTFS format data into appropriate structures suitable for use in the program, we developed our algorithm, which consists of the following blocks: Add points and stops to the route; Place stops on the route; Combine points and stops with the route; Remove duplicate points; Create a route for display; Create route lines in the form of geodata; Create auxiliary route data. This algorithm allows you first to get the points of the selected route, then get the stop points on it and combine this data so that the stops are already on the route and not separately.

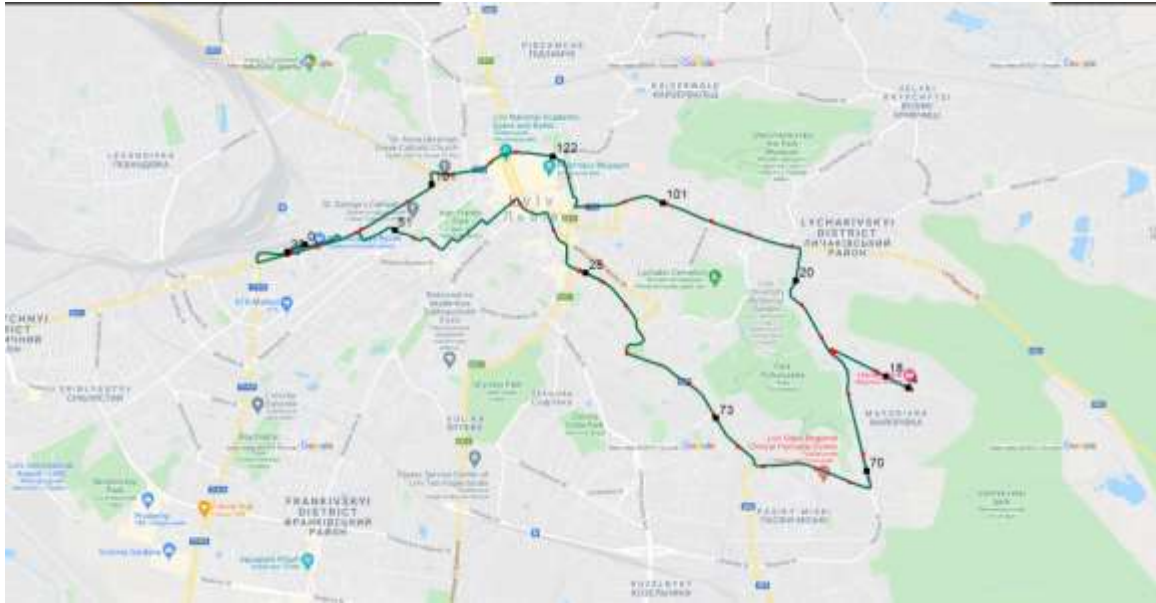


Figure 1: Visualization of "on the map" mode



Figure 2: Visualization of the schematic mode

It also allows you to get rid of redundant points and create geodata lines for later use in calculating a 2D visualization of the movement of vehicles on a route. An example of the appearance of the described algorithm in the code is given below.

```

route.add_points(directions)
route.add_stops(stops)
route.make_stops_on_points()
self._combine_points()
self._combine_stops()
self._delete_same_points()
self._create_for_render()
self._create_geo_lines()
self._create_indexes_and_shortcuts()

```

There are three main classes to represent the essential structural elements of visualization: Stop, Line, and Vehicle. All these classes inherit the parent class Sprite, the arcade module. Rightful inheritance made it possible to obtain all the necessary capabilities for displaying these elements on the screen. Its scheme is shown in Fig. 3.

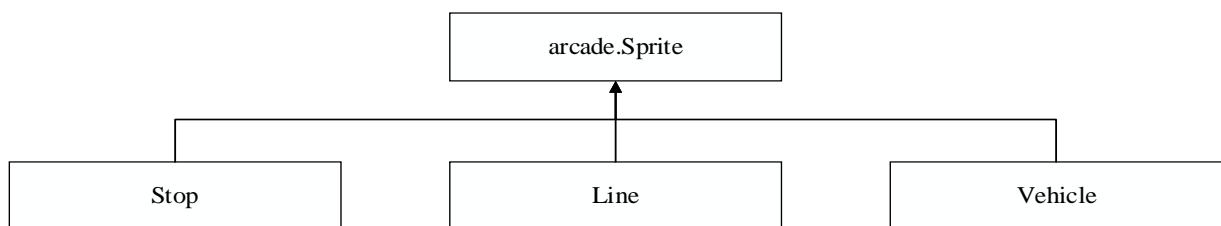


Figure 3: Mapping the inheritance of the Sprite class

5.2. Implementation of forecasting of new passenger flows

Forecasting new passenger flows are done with the help of a neural network built on fully connected layers using the RMSprop algorithm for training. The size and composition of the neural network are constant and do not depend on the size of the data set on which training is performed. The following code snippet creates this network:

```
model.add(keras.layers.Dense(24, input_dim=4, activation="relu"))
model.add(keras.layers.Dense(48, activation="relu"))
model.add(keras.layers.Dense(96, activation="relu"))
model.add(keras.layers.Dense(192, activation="relu"))
model.add(keras.layers.Dense(384, activation="relu"))
model.add(keras.layers.Dense(192, activation="relu"))
model.add(keras.layers.Dense(96, activation="relu"))
model.add(keras.layers.Dense(48, activation="relu"))
model.add(keras.layers.Dense(24, activation="relu"))
model.add(keras.layers.Dense(2))
```

The diagram of the developed neural network is shown in Fig. 4.

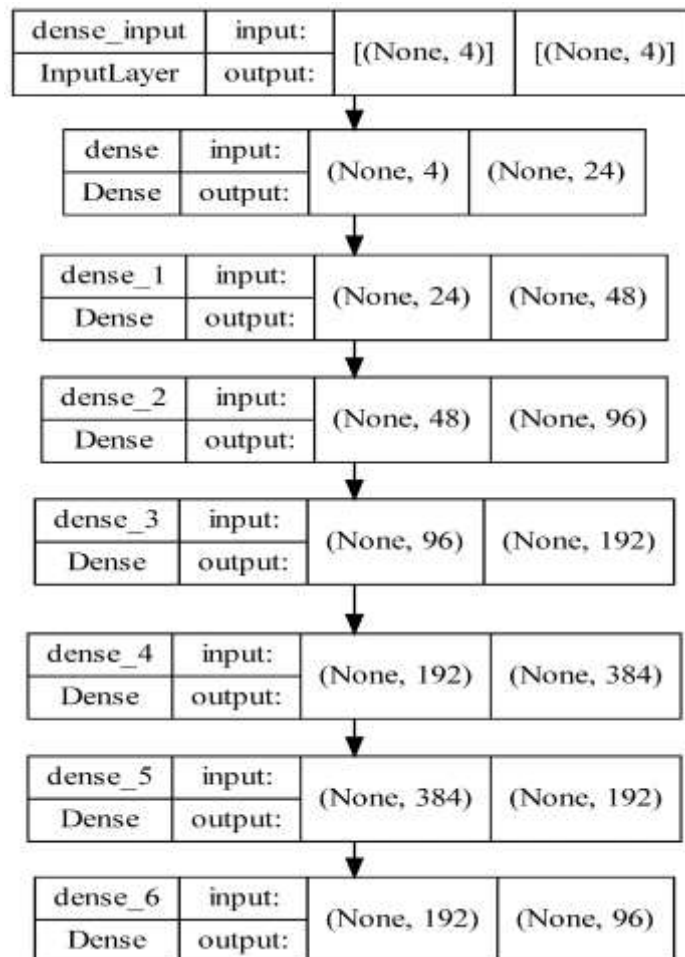


Figure 4: Scheme of the structure of the created neural network

A separate database is used to store GTFS data in the software product. The clearly defined structure and architecture of this database allow you to reliably and correctly store the GTFS data format with the possibility of further quick interaction during the operation of the software tool. An example of building a structure is shown in Fig. 5, which shows the main tables available in the GTFS data type standard.

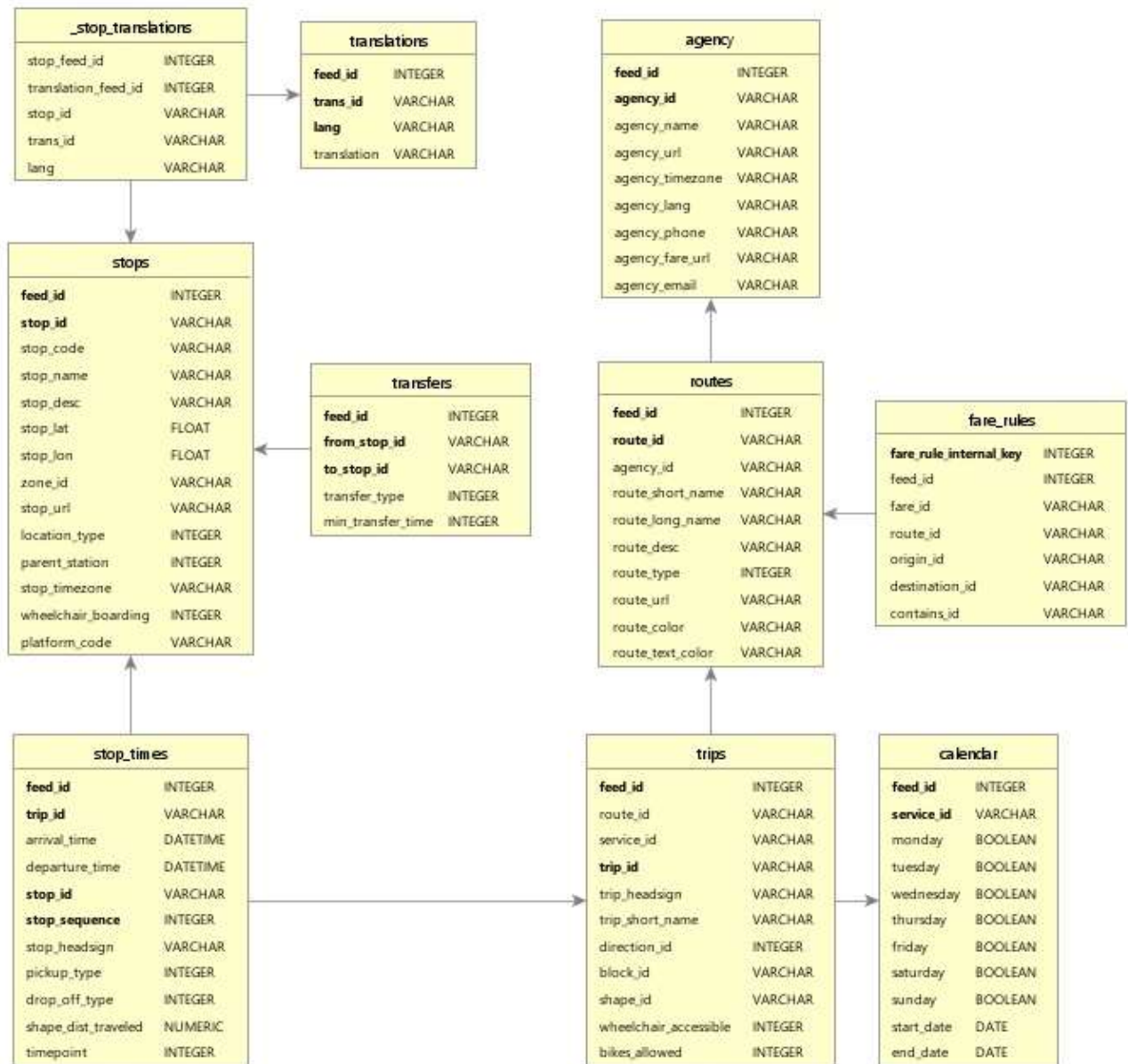


Figure 5: Schema GTFS database

5.3. Requirements for equipment, input and output data

We developed the software product on the Windows platform with an Intel Core i5-6500 processor. According to the obtained results, you can use either an equivalent processor from another manufacturer or even a slightly less powerful processor since the performance of this processor was chosen with a margin. In this case, one of the noticeable problems can only be an increase in the time for calculating some preparatory stages of working with the data. For example, Table 2 shows the number of frames when using the software for a long time, and as you can see from the table, there is no memory leak or loss of performance. The program can be launched by selecting an executable file or a shortcut to the program if the user does so. When opening, the user will always see the program's main menu, which will be displayed in full-screen mode. There are two general types of input data provided for this software product. The first type includes data on vehicle routes, their initial schedule, and stops, which are provided in the style of the GTFS international standard.

Table 2

The number of personnel during long-term work

Time since launch	Number of frames
0 min	522
5 min	501
10 min	518
15 min	506
20 min	509
25 min	495
30 min	507

The Excel file format provides the second data format in which passenger count data is provided. This format was chosen due to its ease of completion by, in principle, any person who will receive or collect this data. Excel data presentation is also used to fill in information about the changed route schedule.

The GTFS format is saved in an archive with a zip extension, and the data files in this archive are in CSV format with a .txt extension. Excel files, of course, have their xls or xlsx extension.

In general, the software generates output data in two forms. The first is a temporary template for filling in passenger flow data in Excel. And the second is the visual view of the submission, which uses schematic mode and "on the map" mode. And in the schematic mode, there is also an opportunity to create an additional display in the form of various graphs.

6. Discussion

After launching the software product, the user is greeted by a full-screen interface where the main tools (buttons) for interaction are placed. The user immediately gets access to the sequential use of the program menu to start the rendering.

The user can select an archive with data in GTFS format at the first stage. After that, the selected file's name will appear, and the option to download this data into the program and in the future. This data will be saved and will not need to be downloaded constantly, but only when it is changed.

The next step after pressing the button "Load GTFS data" is the animation of data loading, which helps the user to understand that the process is going on and that it is necessary to wait for it to complete successfully. It gives the user the feeling that the program is not frozen but is working normally.

An example of displaying animation is shown in Fig. 6. After successfully downloading all the data, the user can use the "Get routes" button. This action will allow the program to load the available list of all routes and immediately select the first.



Figure 6: Download GTFS files

Also, the full name of this route is placed on the screen as text in the button instead of the inscription "-NO ROUTE-". When clicking the button, which now displays the name of a particular route, for example, the route "A01 - Dublyany - pl. Halytska", a complete list of routes will open. This list can be scrolled with the mouse wheel to select the desired one.

The program has a dialogue box containing a complete list of routes that can be selected. The "Load Maps" button allows you to load maps for background display in "on-map" rendering mode. In general, the software product includes maps of the city of Lviv. Therefore, such an action can also update these maps if such a need arises.

The next step in using the program for the user is the ability to use the "Download selected route" button to process the data of the selected route for further use. Since this process is also not instantaneous, the animation of this process is displayed during this loading. It doesn't take much time, only a few dozen seconds at most.

After successfully uploading the data of a specifically selected route, the user can choose to create an Excel file to fill it with passenger flow data on the selected route. As a result of pressing the "Create Excel file" button, a file will be created with the name of the selected route, for example, for the one selected of route A15, the file "A15.xlsx" will be created.

After that, the user can fill this file with relevant passenger flows for further visualization. A fragment of the completed file is shown in Table 3.

Table 3

A fragment of the completed file with passenger exchange

Bus stop	Arrival time	Departure time	Break	Entered	Exited
Bus stop K1	06:29:45	06:30:15	No	39	0
Bus stop K2	06:32:49	06:33:11	No	3	0
Bus stop K3	06:35:50	06:36:15	No	11	4

By pressing the "Visualization on the map" button, we will receive the corresponding visualization of the route with moving vehicles on the screen, shown in Fig. 7.

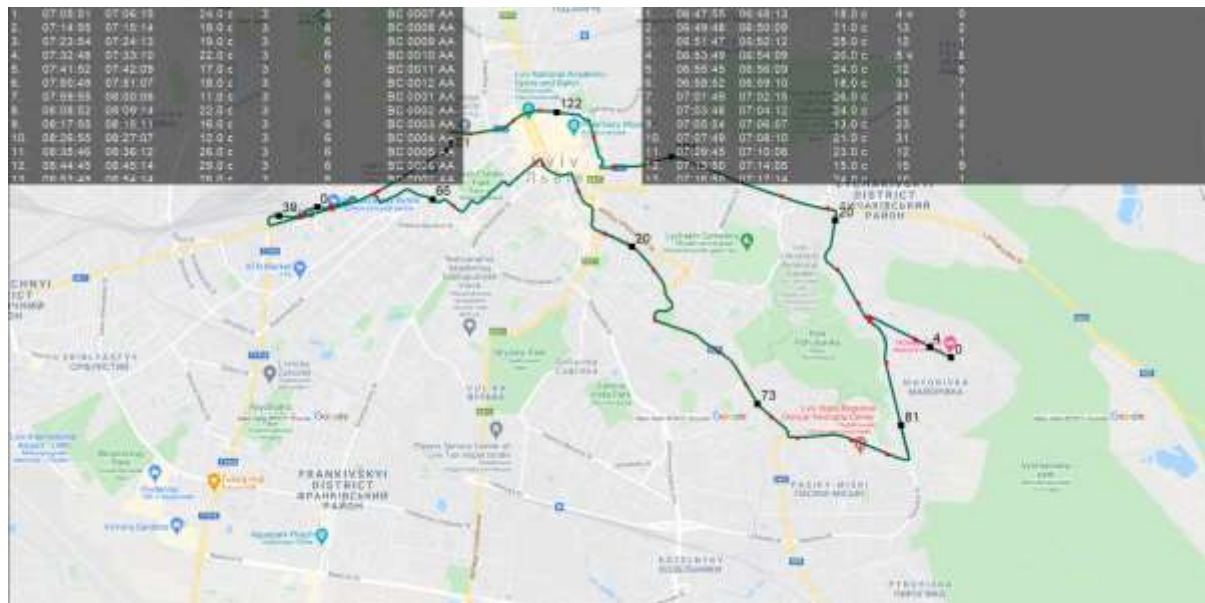


Figure 7: An example of the view of visualization "on the map"

In this mode, stops and transport units can be selected, opening additional information (Fig. 8-9).

In the "on the map" mode, stops are marked with small red squares, and vehicles moving along the route are shown with larger black squares. The numerical value of the number of passengers in the cabin is displayed next to the vehicle mark.

This visualization method of passenger flows allows you to increase and decrease the scale of displaying the route and vehicles. For example, the smallest scale is shown in Fig. 10. The largest scale of visualization of passenger flows on the map is shown in Fig.11. It is worth noting that in the upper right corner of the visualization screen, there is a clock indicating the time at which the visualization itself takes place (Fig.12).



Figure 8: Information window about the selected bus stop



Figure 9: Information window about the selected vehicle

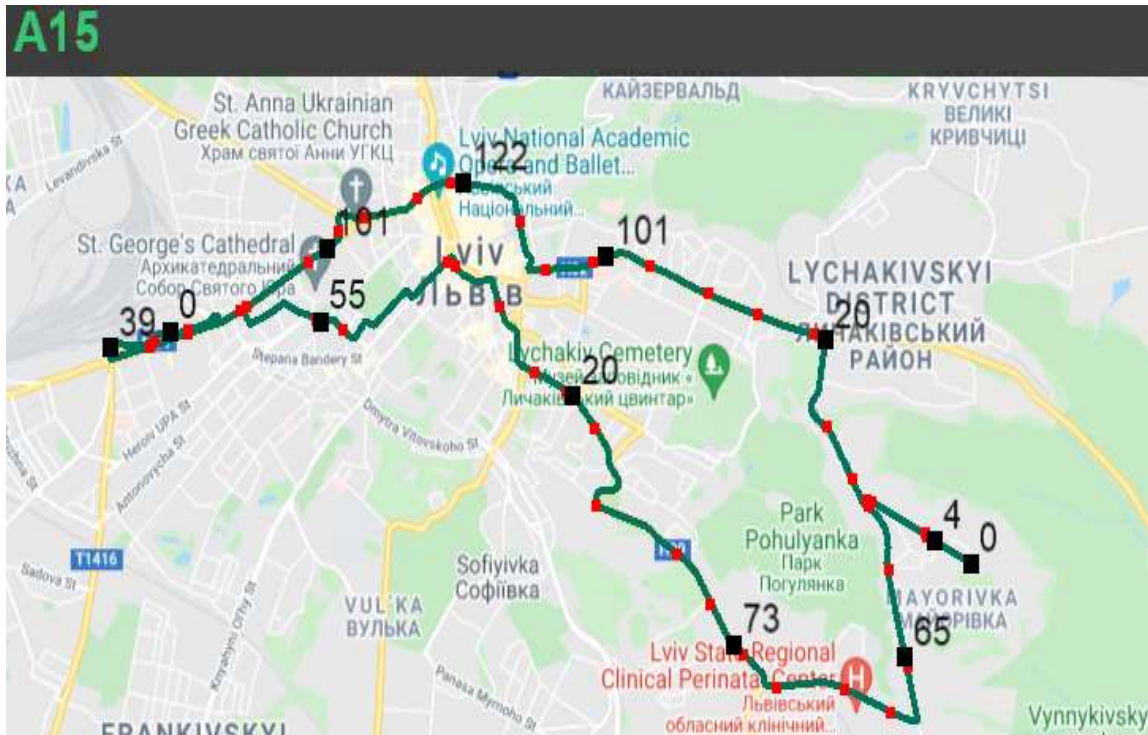


Figure 10: The smallest display scale of the visualization of passenger flows

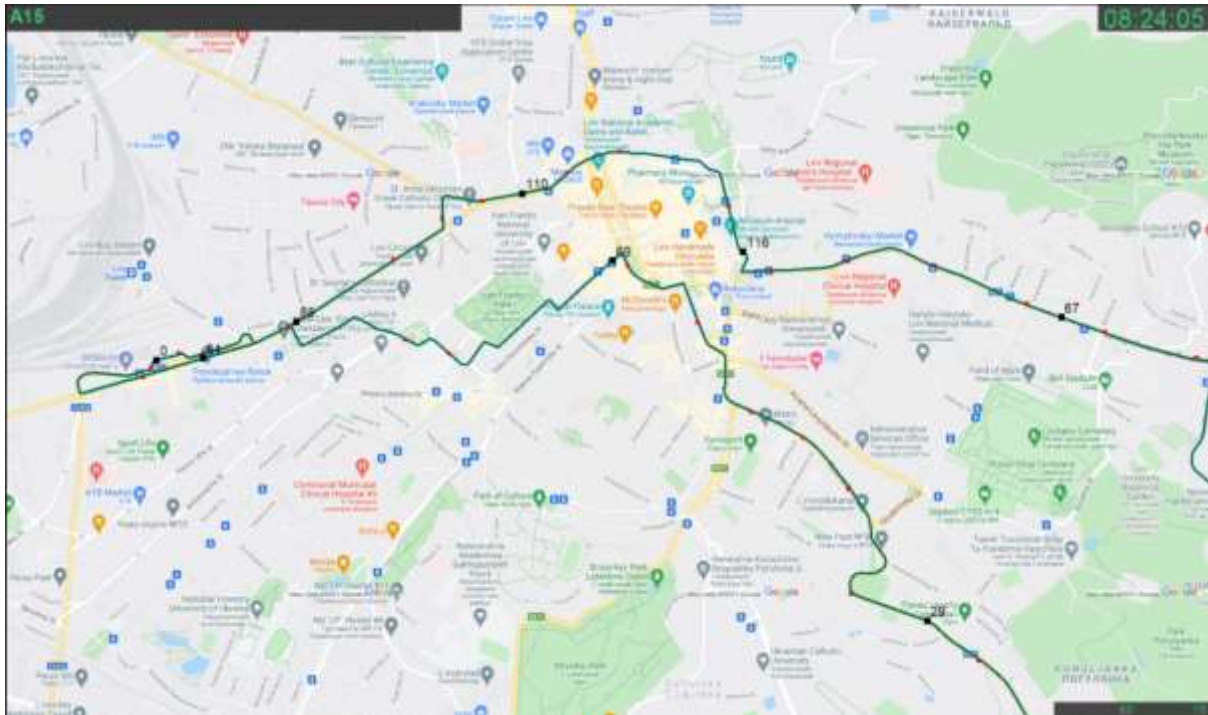


Figure 11: The largest display scale of visualization of passenger flows



Figure 12: Clock in the upper right corner

By default, the program sets the speed of visualization of the movement of vehicles on the route, where 1 second of real-time is equal to 1 minute (60 seconds) of program time. It can be increased or decreased. An example of this is shown in [fig. 4.20](#) and [fig. 4.21](#).



Figure 13: The value of speed and scale



Figure 14: Increasing the speed value

When clicking the "Schematic mode" button, the user will receive a schematic visualization of the route on the screen, where the stops are shown in circular diagrams, and the races are shown in wide strips (Fig. 15).



Figure 15: General view of the schematic mode of visualization of passenger flows

The passenger flow visualization screen in schematic mode consists of three main parts: the route line, the information panel about a stop or run data, and general information about the entire route.

The route line is the first element placed on top of the screen (Fig. 16). It consists of all the stops at which the total passenger turnover is indicated in the middle of the circular diagram, below the signature of the number of passengers who entered and left and the name of this stop with a unique number.

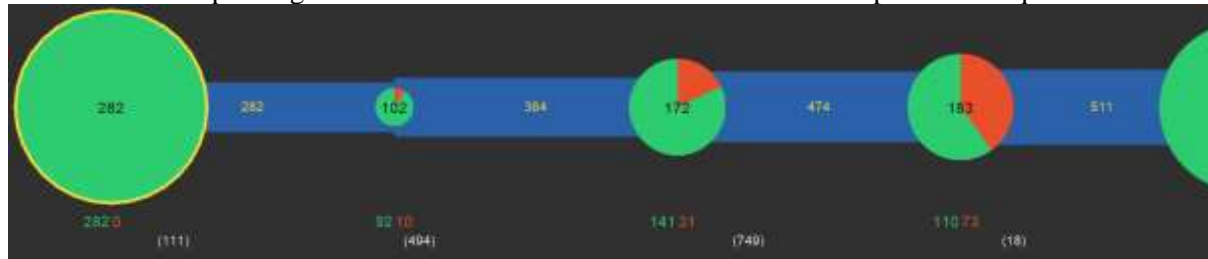


Figure 16: Route line

The green color on the circular diagram of the stop (Fig. 16) indicates the value of the number of passengers who entered the vehicle, and the number of passengers who left relative to the total value of the passenger turnover is marked in red. The circle size of each stop is calculated as the largest passenger exchange on the route. Overrun is indicated by a blue strip between stops (Fig. 16), on which the numerical value of the passenger flow is displayed. The lane's width depends on the ratio of the value of the current passenger flow to its maximum value on the entire route.

The second element of the schematic interface of the mode is detailed information about the stop selected by the user (Fig. 17) or overtaking (Fig. 18).

Зупинка: Приміський вокзал (111)					
Зайшло:		282 (31.33) чол.		Заг. час стояння: 189.0 с	
Вийшло:		0 (0.0) чол.		Сер. час стояння: 21.0 с	
Пасажиروبіг:		282 (31.33) чол.		Кількість рейсів: 9 шт.	
№	Прибуття	Відправлення	Стояння	Зайшло	Вийшло
1.	06:29:45	06:30:15	30.0 с	39 чол.	0 чол.
2.	08:17:48	08:18:09	21.0 с	67 чол.	0 чол.
3.	10:05:55	10:06:13	18.0 с	30 чол.	0 чол.
4.	12:33:50	12:34:06	16.0 с	25 чол.	0 чол.
5.	14:21:53	14:22:10	17.0 с	32 чол.	0 чол.
6.	16:09:52	16:10:14	22.0 с	12 чол.	0 чол.
7.	17:57:49	17:58:14	25.0 с	52 чол.	0 чол.
8.	19:45:55	19:46:10	15.0 с	12 чол.	0 чол.
9.	21:33:50	21:34:15	25.0 с	13 чол.	0 чол.

Figure 17: Blocks with information about the selected stop

The interface's upper part contains the stop's name and code. Below, on the left, there are data on the number of passengers who entered and exited at the selected stop and the total passenger traffic. In parentheses is the average value of each parameter relative to the number of times a given vehicle made a stop during a working day. To the right of it is a block with information on the total parking time of the vehicle at this stop for the entire working time on the route, the average parking time, and the number of completed flights. Below is a block with detailed decoding of data for each flight made.

The race interface has a similar structure (Fig. 18). It contains the name of the race at the top of the blocks, and at the bottom left is a block that indicates the total passenger traffic for the working day, the average passenger traffic relative to the number of flights performed, and the length of the race path.

The block on the right displays information about the vehicle's total time on this route, the average travel time, and the number of completed trips. The large block below describes each performed flight in detail, adding an indicator as the average speed with which this vehicle moved in this race.

Перегін: Скриня (494) - Привокзальний ринок (749)							
Заг. пасажиропотік:		364 чол.		Заг. час проїзду:		1428.0 с	
Сер. пасажиропотік:		40.44 чол.		Сер. час проїзду:		158.67 с	
Довжина:		305.83 м		Кількість рейсів:		9 шт.	
№	Початок	Закінчення	Проїзд	Швидкість	Пасажиропотік		
1.	06:33:11	06:35:50	159.0 с	1.92 км/год	42 чол.		
2.	08:21:07	08:23:46	159.0 с	1.92 км/год	71 чол.		
3.	10:09:10	10:11:51	161.0 с	1.9 км/год	33 чол.		
4.	12:37:07	12:39:48	161.0 с	1.9 км/год	28 чол.		
5.	14:25:15	14:27:46	151.0 с	2.03 км/год	38 чол.		
6.	16:13:10	16:15:54	164.0 с	1.86 км/год	26 чол.		
7.	18:01:07	18:03:48	161.0 с	1.9 км/год	73 чол.		
8.	19:49:12	19:51:48	156.0 с	1.96 км/год	25 чол.		
9.	21:37:09	21:39:45	156.0 с	1.96 км/год	28 чол.		

Figure 18: Blocks with information about the selected run

The third element of the public interface of the schematic mode is general information about the entire route (Fig. 19) of the selected vehicle: duration of working hours of drivers, duration of movement (duration of the vehicle in motion), good mileage of the machine, operating speed, connection speed, technical speed, the number of stops made by the vehicle on the route, time spent at stops or breaks, time spent purely on breaks, and waiting time at stops.

Загальна інформація	
Тривалість робочого часу:	15 год 50 хв 26 с
Тривалість руху:	10 год 50 хв 19 с
Корисний пробіг машини:	170.286 км
Експлуатаційна швидкість:	10.75 км/год
Швидкість сполучення:	13.11 км/год
Технічна швидкість:	15.71 км/год
Кількість зупинок:	385 шт.
Час на зупинках чи перервах:	05 год 00 хв 07 с
Час на перервах:	02 год 51 хв 07 с
Час на зупинках:	02 год 09 хв 00 с

Figure 19: Block with general information about the route

The two upper blocks are shown in Fig. 20, clicking on them with the mouse will open graphs of passenger traffic at the selected stop. The first block will open the schedule of passenger traffic for each flight (Fig.20), which is displayed in the form of bar charts with the average values of each indicator indicated by a dashed line. For an easier understanding of the graph, it shows a legend with an explanation. The second block opens a diagram of the time spent by the vehicle at a stop during each trip (Fig.21), with a dashed line of the average value, which allows you to estimate at which stops the transport unit is delayed. The corresponding graphs are also called from the same blocks only for race data (Fig.18) shown in Fig.22 and Fig. 23.

The prediction function is implemented using a neural network. The user must click the "Teach a neural network" button to activate it. The program will enter training mode, and the user will be shown the loading screen (Fig. 6).

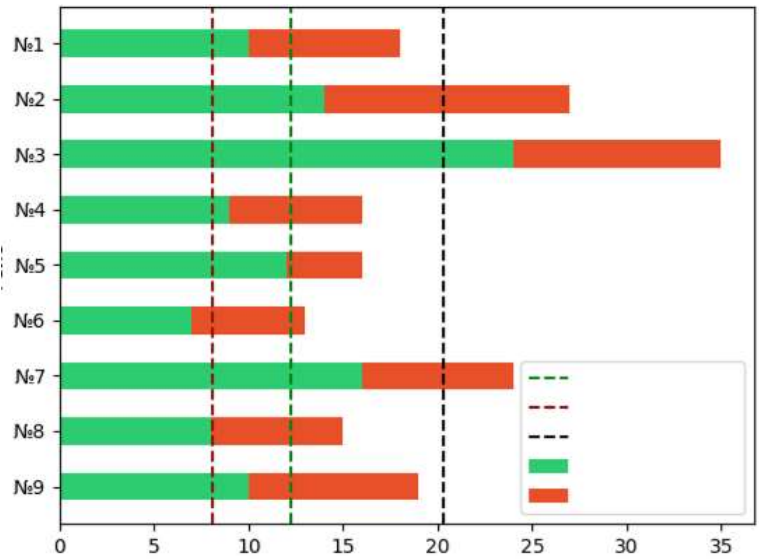


Figure 20: Passenger traffic schedule at the bus stop

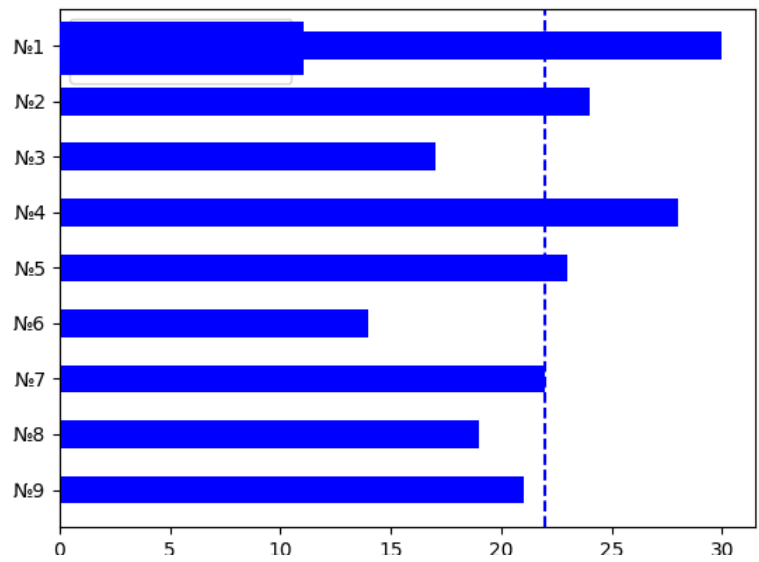


Figure 21: Vehicle waiting schedule at the stop

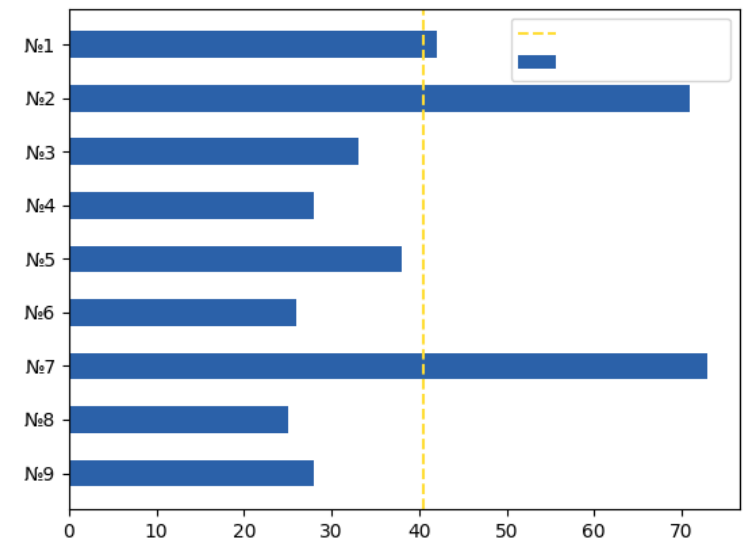


Figure 22: Schedule of passenger flow on the race

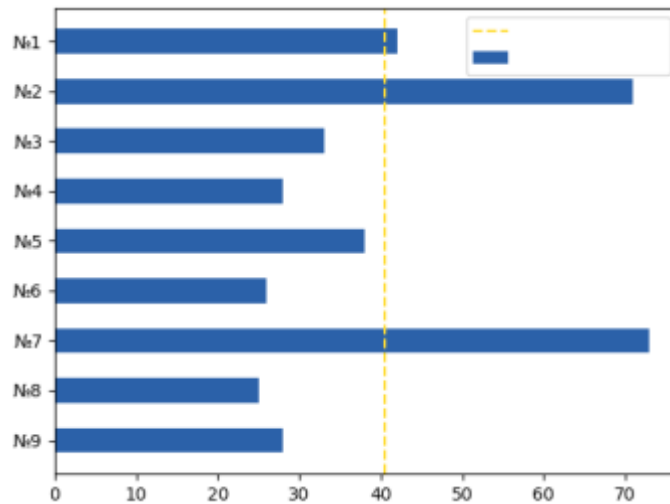


Figure 23: Schedule for driving a race vehicle

After that, the file (in this example for the previously selected route) "A15_new.xlsx" will be created. The user fills this file with a new vehicle schedule (Table 4). A fragment of the completed file is shown in Table 4.

Table 4

A fragment of the completed file with a new schedule

Bus stop	Arrival time	Departure time	Break
Bus stop 4848	06:29:45	06:30:15	No
Bus stop 4703	06:32:49	06:33:11	No
Bus stop 44814	06:35:50	06:36:15	No

After filling out the file, the user can select the "Visualize schematically" button. Subsequently, after a short download, data prediction will occur, and a new view of the schematic mode with all the functions described above will be displayed (Fig. 24).



Figure 24: Schematic mode view with projected data

The diagram of changes in passenger flows in connection with the adjustment of the route schedule is shown in Fig.25. The orange line shows the predicted passenger flows, and the blue line shows the actual ones. This presentation of the data makes it possible to assess whether the schedule change will be favorable from the point of view of increasing the number of transported passengers.

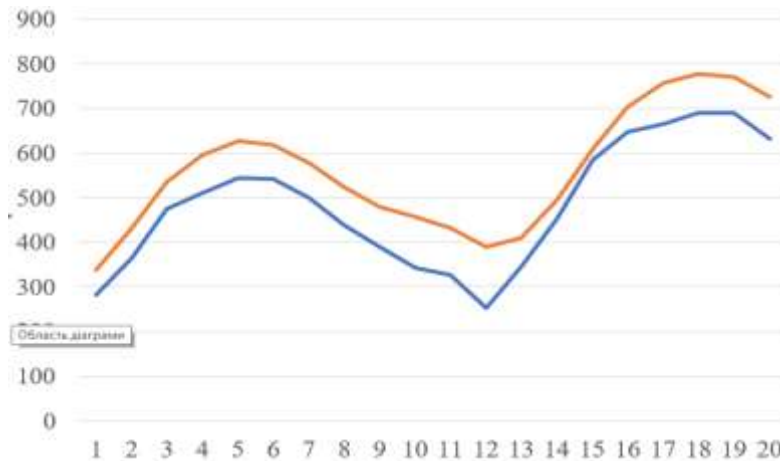


Figure 22: Passenger flow change schedule

So, the description of the developed software tool for 2D visualization of passenger flows according to the requirements and norms of international software description standards is presented.

The analysis of the obtained results of the control example of 2D visualization of passenger flows in a dynamic model based on OpenGL was carried out. The obtained results confirm the developed software tool's functionality and prove the results' relevance to the assigned task.

7. Conclusions

The problem of dynamic 2D visualization of passenger flows in the conditions of the modern development of society has gained considerable relevance in the development of intelligent systems aimed at the modernization of transport technologies in the field of public transportation. To improve the attractiveness of public transport for city residents, a software product has been created that allows you to visualize passenger flows. In practice, this software product will help increase the quality of passenger transportation within the city. The work solved several tasks to create an intelligent system that would improve the provision of transport services in public transportation.

Available and well-known scientific developments and literary sources are studied and analyzed, highlighting the advantages and disadvantages of various algorithms and methods, approaches, and tools for solving the problems of 2D visualization of passenger flow in cities. As a result of these studies, a clear interaction between the factors and criteria that can be used to evaluate the quality of transport services for the transportation of passengers was found, which indicates the relevance of the study of passenger flows, as well as the visualization of public transportation. It was established that the concept of passenger flows is an aggregation of such concepts as passenger exchange at stops and passenger flows on runs.

As a result of the analysis, the structure of the intelligent system of 2D visualization of passenger flows was proposed. Connections of the system with elements of the outside world have been established. A set of requirements for the system was formed to solve the problem of 2D visualization of passenger flows. It is determined why the system is needed and what is the essence of improving the quality of providing passenger transportation services on public routes in cities.

It is substantiated that the target stakeholders for implementing the system are state, communal, private companies, and enterprises that provide public transport services. From the passengers' side, the proposed intelligent system helps reduce vehicles' overcrowding and improves transport units' schedules.

Since the analysis of passenger flows is a non-trivial task of transportation, at the stage of development of an intelligent system for visualization of these passenger flows, problems related to the choice of programming language, appropriate auxiliary libraries, and effective databases were successfully solved. The work substantiated the feasibility of choosing the Python programming

language with the main modules arcade, geopy, matplotlib, multiprocessing, openpyxl, pygtfs, and TensorFlow for 2D visualization of passenger flows. With the help of OpenGL, low-level communication with the rendering of graphic elements was provided. A thorough analysis of other modules was carried out, and only those that provide the most excellent efficiency for the created system were selected. A unique role in the software was assigned to use the GTFS format, an internationally recognized standard for submitting public transport route data. This made it possible to make the created product more universal. Unique proprietary algorithms have been developed to create a visualization in two modes: schematically and "on the map". In the second mode, the method of calculating vehicle movement data for visualization on the screen plane was also successfully implemented, taking into account the absolute values of geographic coordinates in the real world, which made it possible to avoid unnecessary errors and rounding in calculations. The work of the developed software tool for 2D visualization of passenger flows, which corresponds to the structure defined by international software description standards, is described.

As a result of the work of the control example of 2D visualization of passenger flows in a dynamic model based on OpenGL, the functionality of the developed software product was confirmed, and the results were proven to meet the tasks. A neural network was created using the RMSprop learning algorithm, which predicts how the passenger flow will change when the vehicle schedule is changed on the route. The obtained results make it possible to justify the feasibility of adjusting the vehicle's schedule on the route for more efficient use of the route sections during peak times.

8. References

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